Heat and Human Health Workshop, Exeter 4th to 6th April 2011

For: the University of Exeter and the Met Office
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† from September 2011

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Summary

The Heat and Human Health workshop provided the opportunity for an interdisciplinary and international discussion on the evidence for the impact of heat on human health, the value of delivering services to reduce morbidity and prevent mortality, and the potential of physiological models to facilitate the development of targeted services. Based on the recommendations of the workshop participants, a list of suggested collaborative research proposals can be found in the last section of this report.

Recommendations

1. **The aims of the research resulting from the Heat and Human Health workshop are:**
    a. **Improving the health and quality of life of vulnerable people**
    b. **Avoiding excess mortality and morbidity**
2. **Research proposals should ensure that the following are addressed, to avoid duplication and promote value-for-money:**
    a. **Reviews, meta-analyses and epidemiology**
    b. **User value and involvement, service delivery and effectiveness**
    c. **Physiological models and their outputs, indices and thresholds**
3. **To achieve the aims in one, research should address the following:**
    a. **What is the thermophysiological response of a vulnerable individual to heat/cold?**
    b. **What are the cardiovascular and respiratory risks from heat and cold stress, how are these caused and how can these be reduced?**
    c. **What is an acceptable quantified threshold for heat inside a building?**
    d. **What is the relationship between output from physiological models and the effects on vulnerable populations?**
    e. **What are the preventative measures that could be taken to reduce morbidity and prevent mortality in individuals sensitive to heatwaves?**
    f. **How will the health-risks change as a result of a changing climate?**

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1. Introduction

The Heat and Human Health workshop was held at the University of Exeter (United Kingdom) from 4th to 6th April 2011. It was attended by 24 participants from 7 countries (France, Germany, Japan, Korea, Sweden, the United Kingdom and the United States of America). The workshop brief, concept and objectives* are reproduced here. The overarching principle of the workshop was that '*Understanding the physiology behind heat and cold-related illnesses can help us alleviate the effects of adverse weather on human health*'.

Workshop brief

Modelling the physiological mechanisms involved in heat and cold-related illnesses would provide a greatly improved understanding of the risk of adverse weather on human health. The University of Exeter and the UK Met Office propose to work with each other and with other leading organisations to research the effect of temperature related environmental parameters (heat and cold) on human physiology. The aim of this workshop will be to define a robust model of thermo-physiology that can be employed in further research.

We know that heat and cold kill, and that epidemiological studies provide some answers to the questions of how this happens and why. However, epidemiology alone does not go far enough. Together, we would like to engage with experts in the fields of temperature related effects upon the human metabolism, and in particular the cardiovascular and respiratory functions. Specifically, the field of interest is the physiological response of the human metabolism to environmental conditions (e.g. changes to blood flow due to temperature) and the mathematical and computational modelling of the human physiology responding to its environment.

This expertise will help formulate the research questions to be addressed – and in turn these questions will provide direction to the research effort in this field. By combining this knowledge with the expertise in weather, risk analysis, forecasting and health impacts of climate change that exist at the Met Office, it is hoped that a thermo-physiological model can then be used in the design of patient interventions, care models, services to vulnerable populations and building design and management. The potential deliverables from such research include tools enabling the clinician to assess the physiological risk to patients from given environmental conditions.

* www.exeter.ac.uk/metoffice/heatandhealth

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Concept

Simulating the physiology that links environmental conditions and ill-health would provide a direct method of assessing the health impact of weather, and therefore provide the means for health hazard forecast services. While statistical analyses using epidemiological techniques provide an assessment of the impact of different environmental conditions on human health, simulating the physiology using numerical methods has key advantages: it provides a measure of risk that can be readily explained by physiological processes, and it is an assessment of exposure to hazardous environmental conditions against which mitigating actions can also be assessed using the same methods. An example of a mitigating action could be sheltering, that is a change in exposure from a windy and wet to a still and dry environment – in both situations heat-loss can be evaluated.

Concerning Heat and Human Physiology, the Met Office has primarily three areas of interest: (1) the direct hazard of extreme heat and cold, (2) the risk to the cardiovascular system, and (3) the risk to the respiratory system. For example, arteriolar vasoconstriction due to cold may increase peripheral resistance and blood pressure, placing an extra strain on the heart that will put patients suffering from heart or coronary disease at risk.

Objectives

The bringing together of experts in the field of Human Physiology as it relates to the environment will encourage new international research collaboration. In particular, the workshop will include numerical/computational modellers with experience in simulating aspects of Human Physiology. The workshop will help develop multidisciplinary research between researchers in Human Physiology and physiology modellers.

Participants of the workshop will identify the physiological mechanisms that link environmental conditions to known health hazards including:

1. *physiological mechanisms that require little further research and that can be simulated with existing methods,*
2. *physiological mechanisms that require little further research but which simulation methods would require development, and*
3. *physiological mechanisms that are poorly understood and require significant further research.*

2. State of knowledge presented

Eight keynote speakers provided the background to the state of the knowledge in the field of Heat and Human Health. Their presentations were given in plenary sessions and covered the areas of:

- the impact of heatwaves and the development of heatwave warning services,
- the changing impact of cold and heat on human health with climate change and in different environments,
- the thermophysiology changes due to circadian and seasonal effects and for vulnerable population groups, and

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- the modelling of the human thermophysiology.

These plenary keynote presentations were organised to help bridge any gaps between fields of expertise and encourage the multidisciplinary and international characteristics of the workshop. What is printed here in this section consists of neither a reproduction of the materials presented by the speakers nor of abstracts of these materials. What is reported here is the information presented by the keynote speakers as it was minuted at the Heat and Human Health workshop with the hope that adds to the information available in the speakers' presentations and records the discussions at the workshop.

We are very grateful that these plenary sessions were chaired by George Havenith.

'*What happened during the Paris heatwave of 2003?*'

Gerald Kierzek *(keynote speaker 1)*

Gerald Kierzek presented what happened in Paris during the heatwave of 2003 from a clinical viewpoint, and what changed as a result in terms of surveillance and prevention.

The databases of two hospitals in the centre of Paris, Hotel-Dieu and Cochin, were used to provide admissions data (> 100 000 visits per year, medical and surgical). These two hospitals provide a good reflection of hospitals in Paris. The heatwave started on 1st August 2003 with a first alert by Meteo France that was purely meteorological and with no connection with the potential health impact. On 4th August hospital admissions started to increase and in the period 4th to 10th August there was a small increase in heatstroke but a huge increase of admissions and deaths that were heat-related and not acute heatstroke, especially in the elderly. On 11th August the media were alerted by the hospitals and on the 12th a disaster plan (plan blanc) was put in place, one day before the end of the heatwave on 13th August: the assistance for the crisis was put in place 11 days late.

Cumulative excess deaths reached 14,800 in the first two weeks of August, equivalent to a +60% increase in mortality. This was +120% for the over 50 year olds – noting that 50 is not particularly old – and +170% for the over 85 year olds. There was also an increase in admissions and attendances such that emergency attendances were used for alerting after 2003.

There was incapacity of emergency departments to react in a heatwave due to the delay in information and to logistical problems. Mortality was measured purely retrospectively (not real time) and there was no health watch for heatwaves, hence no prevention was possible. Emergency departments are at the heart of the health system and populations attend hospital because of problems external to the hospital such as heatwaves. There was a lack of beds and of capacity in the mortuaries, and the hospitals were overworked and unable to manage the situation: hence the crisis.

A health warning system was put in place after 2003. An alert system from emergency departments to national level provides quantitative monitoring with, in Paris, real-time monitoring of crowding in hospitals (computerised) by 90

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emergency departments and 8 SAMU (emergency response services). A centralized network is being set up nationally. In Paris, daily real-time attendances are reported for 15 to 75 year olds and over 75 year olds, with surveillance of global activity from pre-hospitalization to intensive care unit. Syndromic surveillance in hospitals provides quantitative monitoring, with first diagnoses in triage in conjunction with other symptoms (e.g. temperature, abdominal, respiratory, etc.). This provides a wider view: emergency services are used as a health observatory. In addition, a heat-health watch system based on weather forecast from 1st June to 31st August provides heatwave alerts to hospitals. Applying the syndromic data retrospectively to 2003 showed that it would have been possible to predict the situation on 5th August 2003. This data is also used for influenza-like illnesses in the Winter to predict epidemics of flu, and could also be used for unknown risks such as bioterrorism, etc.

The heatwave plan consists of levels 1, 2 and 3, the latter a trigger for hospitals to take action. Mortality outside hospitals, after 2003, could be predicted based on age, temperature and admissions, and enabled the creation of an index (PIREM) which would have provided a good indication of the 2003 heatwave.

Use of sociological data in the United States of America showed that patients that are poorer, older and more isolated are more affected by heatwaves, but these factors are not necessarily aggravating in Europe. Clinically and physiologically, acute thermal shock causes dysfunction of the central nervous system. But in France 2003, patients suffering from heatstroke were far fewer than those suffering from heat-related symptoms. Data on causes of deaths found that 58% (8584) victims died outside hospital. In-hospital patients with heatstroke resulted in 60% mortality and many survivors with permanent neurological damage.

The review by Bouchama et al.[1] (2007) identified that psychiatric, cardiovascular and pulmonary illnesses were associated with higher risk of death in heatwaves, while social contact (visits), fans, air-conditioning and showers were associated with lower risk. This was compared with the French heatwave with data from 16 emergency departments for patients with temperatures > 38.5 ℃ with a 1-year follow-up. The mean age was 79 ± 19 years, 47% with temperatures > 40 ℃ and 27% in critically ill conditions. Only 88% were diagnosed with a heat-related condition. Survival rate after 1 year was lower than expected at 57%. 35% of deaths were of persons that had been completely autonomous. 11 variables were found significant in the multivariate analysis, including age (> 80), living in institution, white blood cells > 14 000 /mm^3 and infection (e.g. pulmonary).

In conclusion, there are now 3 health warning levels in hospitals: (1) no crisis, (2) no crisis but anticipated situation (e.g. World Cup), (3) crisis that is abnormal and non-anticipated. This provides early detection and the possibility for prevention.

Discussion[*]

It was asked why the health warning system used real-time data: this would be too slow and ideally forecasts (and not nowcasts) should be used. It was noted

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that this is not only a meteorological problem and that the system is also used for other risks. It was observed that there was no monitoring of young casualties as only > 15 year olds data were monitored. It was also observed that survival rates were low: there is no explanation for the underlying cause of this and it was noted that risk factors in European heatwaves were different to those in the United States of America. The proportion between deaths and attendances was queried: the two were comparable with a statistical link so that what happens in emergency departments can predict outside hospital deaths.

'*The development of heatwave warning systems in Korea*'

Gwangyong Choi *(keynote speaker 6)*

Abstract

The elderly cohort is evaluated as the most vulnerable age group to heat wave-induced casualties. Recent aging trends of the world population are increasing a concern with the occurrences of unprecedented, catastrophic human mortality by super heat waves in a warmer climate. An understanding of geographical and societal differences in human resilience to different levels of heat waves is essential to develop proactive heat wave warning systems for future generations in the changing climate. This study introduces the history of how heat wave warning systems in Korea have evolved. Also, what should be updated to improve the current warning systems is discussed. In the early 2000s, heat wave warning categories were first suggested based on human mortality in Korea. Choi (2006) classified four categories of heat waves based on the size of human mortality with respect to the daily variations of high apparent temperature. As a result; three consecutive days with at least 32.5 ℃*,* 35.5 ℃*,* 38.5 ℃*, and* 41.5 ℃ *of daily maximum heat index (DMHI) were defined as the Hot Spell, the Heat Wave, the Strong Heat Wave, and the Extreme Heat Wave days, respectively. Similarly, the Korea Meteorological Administration (KMA, 2007) defined a heat wave episode as the case that daily maximum temperature exceeds* 33 ℃ *with DMHI equal to or greater than* 32 ℃ *during two consecutive days. However, a heat wave definition based only on daily maximum temperature has been popularly used by Korean weather forecasters in the mass media. Moreover, the difficulty in predicting accurate humidity made temperature-only definition preferred even among the KMA experts. However, Choi (2006) claimed that high humidity under the moist East Asian Summer monsoon can contribute to the increase of human sensible temperature up to* 4-9 ℃*, accentuating the usefulness of heat index. According to the investigation of 100 year observations (Choi, 2010), the 1994 heat wave is evaluated as the most catastrophic event with human mortality exceeding 3,000 across Korea. In particular, the Seoul metropolitan area showed the highest sensibility to strong heat waves during the 1994 episode. Spatially, more excessive mortality was report in the districts with less vegetation within the metropolitan area. This indicates that the preservation of cooling islands such as urban parks can contribute to mitigating the loss of human lives even though the occurrence of synoptic heat waves itself is unpreventable.*

The Korean heatwave warning system was presented by Gwangyong Choi, with its history and the characteristic of heatwaves in Korea. The climatology of heat

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stress and human mortality, with heatwave categories and associated synoptic weather types were presented.

It was first shown that there is no linear trend in counts of days of extreme temperature with time. In the 1994 Korean (Seoul) heatwave case human mortality peaked in July 1994 with 4000 (700) deaths, many of which were from people with chronic diseases with the elderly most vulnerable. These were linked to blood circulation and respiratory problems. In particular, expansion of the blood vessels due to the physiological response to heat makes blood circulation an important factor.

The heatwave warning system KMA-HWWS has thresholds of temperature and Heat Index (HI). Having two parameters makes the system more complicated and is a weakness. The HI is the better parameter because it includes the effect of relative humidity, and it results in fewer overestimations.

There are on average one to six heatwave days per year and, in the worst years, up to 20 extreme heatwave days exceeding 35.5 ℃. The heatwaves were coincident with the holiday Jangma break. Within the hot urban area there were urban cool islands in extreme heat waves, with large differences in land-surface temperatures, e.g. ranging from 23 ℃ to 32 ℃ (in a Landsat TM imagery taken at 10:30 am on 26 July 1994). Heatwaves are generally caused by stationary high pressure systems.

Future work includes improving the heat wave warning system using synoptic conditions, by climate zones and differentiating by city and rural areas. The following questions were suggested:

- How to devise a universal heat wave warning system?
- How much can thresholds vary due to acclimatisation?
- How do heatwaves affect the circadian change in core temperature?

Discussion[*]

It was noted that the temperature threshold used in Korea is high compared to that used in the United Kingdom. A suggestion was made to redefine the heatwave warnings using the UTCI (Universal Thermal Climate Index): however, there was a reluctance to use too many variables.

It was then suggested that how an index is used depends on the actions to be taken: what response should be initiated based on the warning? This is not a simple question, and there are many issues around the cost of doing something versus that of doing nothing, and ignoring warnings when there are too many. It was further highlighted that the heatwave system warning system used is based on temperature and relative humidity and can provide warnings (nationally) in advance, but it may need to be fragmented into smaller geographical areas.

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'*Key issues for calculating heat exchange in different physical environments*'

David Coley *(keynote speaker 2)*

The risk from heat due to buildings (dangerous architecture) was introduced by David Coley. It was noted that homelessness was not a risk factor in the 2003 heatwave. Risks of buildings failing (from fire, flood, etc.) are well documented but none are related to heat or health care.

There is a need to model the environmental situation in and around buildings but there is no information on what the health risks are and how architecture may be changed to mitigate these risks. Sunshine, air flow and humidity can be predicted but the effect of the environment on humans is not normally examined. A statement is needed on the variables and thresholds that are required for human health based on a human model. Up to now, architecture has not been seen as a health care issue, in terms of the problems that buildings may cause.

There are possible mitigation solutions: changing the colour, adding shading over windows, etc.; more ventilation at night (but there are worries about crime that encourage keeping windows closed); increasing thermal mass, changing the building material. There are different responses to heat around the world:

- air conditioning;
- thatch roof, white colour;
- deep well-like buildings, large thermal mass;
- urban shading (narrow streets).

The following questions therefore need to be addressed:

1. What definition of thermal comfort should be used?
2. Will this change as the United Kingdom warms?
3. Is it different for vulnerable groups?
4. How de we put a person into a dynamic thermal model of a building?

The current standard measure of an excessive temperature in a building is > 28 ℃. Is this suitable for vulnerable groups or long periods of relatively warm weather? Will populations adapt and this threshold change with climate change?

Activity and use of household equipment impact on internal conditions. Energy consumption can be predicted as well. Clients require a duty of care and seek low energy usage. Addressing the problem is urgent: the problem is getting worse through the increasing use of glass and lighter weight buildings; and climate change means it is getting warmer – the Summer of 2003 will be equivalent to a normal Summer by 2040 and a cool Summer by 2060. And low carbon buildings that are designed to mitigate climate change might not be very good at dealing with climate change.

Discussion[*]

It was suggested that air conditioning could be good for health and that a balance was required so as to achieve appropriate heating in the Winter. However, it was asserted glass – even triple glazed – has a very high

[*] Contributions to this discussion from Paul Wilkinson, Mark McCarthy, Mike Tipton, George Havenith, Ken Parsons and Clare Thorn are acknowledged.

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conductivity (heat loss) and even in the Winter much energy was lost at night, more than what was gained in the daytime. This possibly applies more to locations like the United Kingdom and may be different in other countries with more sunshine in Winter. With respect to low carbon buildings, very low heating is required in Winter but they might be a real problem during heatwaves. It was highlighted that most buildings are already built and so air conditioning is used as a last resort. It was noted that low carbon buildings are made to achieve current low carbon targets and may not be achieving low carbon in a warmer climate; there would be a significant problem if most buildings used air conditioning. There may be answers to these adaptation and modelling questions; numbers and thresholds will be needed to be used in building design (or adaptation) which is currently qualitative, and it was suggested that these could be specified.

The question was asked as to why people over-cool buildings: it was acknowledged that it is a real problem in some places (e.g. New York). It was suggested that a change of clothing could help in heatwaves, such as removing ties, etc., though assumptions for the United Kingdom population should not be transferred to other parts of the world (say India). It was noted that cold in Winter causes illness because of the closeness of people with each other keeping warm.

'*Thermoregulatory responses to cold and to heat and associated seasonal mortality*'

Mike Tipton *(keynote speaker 3)*

Mike Tipton presented an overview of the topic of heat and human health, noting that the workshop is interdisciplinary and international. The climate is warming and is expected to rise by ~ 4 ℃ by 2055 to 2070, with an increased potential for acute cold snaps and heatwaves. The global air temperature is 15.4 ℃ and the sea bed temperature 3 ℃. For humans, thermal neutr al conditions exist with temperatures in the range 26 ℃ to 28 ℃. Thus it i s not the mean increase in temperature that will cause problems.

With respect to seasonal deaths, mortality is lowest at 19 ℃. There are more excess deaths in Winter than Summer and mortality rates are decreasing because of improved technology in homes. Cold deaths are associated with thrombi (50%) and respiratory disease (25%), affecting the elderly most. Heat deaths are caused by hyperthermia in hot regions but also thrombi due to sweat loss and cardiovascular strain. In the United Kingdom, global warming is expected to reduce cold deaths by 20 000 and increase heat deaths by 2 000 (per annum).

Models of human thermoregulation exist, interfacing the interactive systems with the passive systems. Yet metabolic response (e.g. shivering) is difficult to model. Simulating human thermoregulation is useful for cold exposure survival models and heat stress indices. The challenges are to differentiate between acute and chronic exposure, between temperature and fluid balance, and to assess the predictive power and sensitivity. Models need to be effective for special populations (e.g. the elderly) and with factors that vary between and within people (illnesses, etc.). In any case models must be based on a strong theoretical foundation and to be of use in the context of this workshop predict not

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only the thermal responses to environmental changes but also the pathophysiological (health) consequences of these changes.

Risk factors for hypothermia and hyperthermia include age, air movement, morphology of body, fatigue, intoxication, etc. Some factors are permanent, some vary between and within persons. For example, there is a vast difference in heat loss with different people in water at 18 ℃. There are well used models with thermal but also non-thermal factors – including reciprocal inhibition[2]. Non-thermal factors are physique, trauma, gender, age, etc. Improved modelling – such as of the vasomotor tone – would help to determine the cardiovascular risk (and other health states outcomes).

In conclusion, the risk due to climate change is not a risk of human extinction – compared with other possible global catastrophes. Extra cold and heat waves may cause an increase in risk of seasonal/periodic mortality, particularly in the elderly. To be of use, models of these responses should be able to take account of the variations in the response of different (vulnerable) groups, and predict health outcomes. A good start to this process would be the development of models that can estimate the relationship between vasomotor responses, fluid balance and the medical conditions associated with changes in circulating blood volume, particularly the likelihood of the development of thrombi (blood clots). At a general level, an impact of climate change may involve the need to redistribute humanity, in terms of global habitat (living regions, farming regions) rather than the current geopolitical/nationalistic divisions.

Discussion[*]

It was suggested that the risk is not only to the elderly but also to all vulnerable people – which includes younger vulnerable groups. However, after further discussion it was acknowledged that there is evidence that the risk is mainly for elderly people though it was acknowledged that there are other vulnerable groups. There was discussion about how the risks will change as the population is ageing.

It was questioned why human beings are not better at coping with temperature variations. The human is still a tropical animal therefore requiring a building. The problem (of heat risk) becomes more important because of excursions from the home: when people do not prepare to go outside, they become exposed to cold (or heat) causing an impact on the individual's health. It was also proposed that poorly insulated homes were a problem. While even people who heat their homes well are at risk when going out, hypothermia occurs as the individual becomes used to a cooler temperature, causing a cardiovascular risk for example. Further, it was mentioned that aerobic fitness may be a factor for heat stress, different to obesity, and the question was raised as to how a model could be built to include the increase in prevalence of obesity. The increase in life expectancy due to medical advances and interventions means that there is less susceptibility to the environment; however, some drugs may impair adaptation to temperature variations. Physiological model responses can be adjusted for

[*] Contributions to this discussion from Ron Maughan, James Goodwin, Mark McCarthy, David Llewellyn, George Havenith, Matthias Heil and Ken Parsons are acknowledged.

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different exercise functions for the healthy, but this is more difficult for the unhealthy.

It was then highlighted that models are of single individuals, and questioned the validity of their applications to populations. Would a statistical model not be much better for populations? If a model has too many parameters, then it is likely that it can fit all observations. It was acknowledged that it is difficult to model humans, but that there is a real risk and that therefore a model is needed. It was confirmed that models are helpful for predicting: the more overwhelming the thermal load the better the prediction. The impact of climate change will be through physiological pathways (generally difficult to model). There is a need for anticipatory care and prevention, to prevent casualties from heat and cold: models are required, even if difficult, because they will provide some way towards a warning. The barrier is between science and knowledge transfer into a warning that is an effective message to populations. In this context it was acknowledged that communication to populations is fundamental. There is a need for modelling to develop a service, e.g. the Met Office COPD service, but not a need for modelling to issue warnings.

The effectiveness of cooling by putting people in water was raised. This was confirmed as very effective but constraining – putting hands and feet in water was effective for cooling. This however is treatment, not prevention.

'*Thermal environments during sleep and daytime; effects of light exposure; and the effects of both on human heat exchange*'

Naoshi Kakitsuba *(keynote speaker 4)*

Naoshi Kakitsuba presented three topics concerning the effect of the thermal environment with respect to the circadian cycle of body temperature.

1. Global warming and urban heat islands have increased the use of air conditioning with the resulting impacts on sleep disorders and catching cold. Experiments were carried out to investigate the effect of air temperature and relative humidity on sleep (and similarly for the effect of air movement). The experiments consisted in an initial ambient temperature of 30 ℃ followed by (at midnight) (i) cooling to 26 ℃ for two hours then back to 30 ℃, (ii) cooling to 28 ℃ and (iii) no cooling 30 ℃. Sleep was from times 0 h to 8 h. EEG and temperature measurements were made; other data were obtained by questionnaire before and after sleep to assess sleep quality. It was found that sleep quality was better with cooling from 30 ℃ to 28 ℃ with a lower core temperature. The optimal thermal environment with respect to the circadian cycle is that which just before sleep increases peripheral blood flow and melatonin levels to induce sleep. Further experiments consisted in (iv) a constant ambient temperature of 28 ℃, (v) a steady decrease in temperature from 28 ℃ to 26 ℃ and (vi) a steady increase in temper ature from 26 ℃ to 28 ℃ from 0 h to 8 h. The latter of these was foun d to be best for sleep quality, while the body has a drive to decrease its temperature during sleep.

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2. This topic examined daytime considerations whereby some physiological functions unavailable during daytime means a diurnal increase in body temperature. Again, three experiments were carried out, consisting in (i) a constant ambient temperature of 28 ℃, (ii) a gradu al increase in temperature from 26 ℃ to 30 ℃ and (iii) a gradual decrease in temperature from 30 ℃ to 26 ℃ from the times of 9 h to 18 h, with 60% relative humidity and a luminosity of 900 lux. It was found that rectal temperature increases in all three conditions in the morning but that rectal temperature change was different in the afternoon, in particular decreasing with the ambient temperature decreasing. ECG measurements were taken and heart rate variability was assessed through the use of FFT (Fourier) for low/high frequency components. Changes in low/high frequency ratio were observed for the different conditions. In conclusion, rectal temperature increases in the morning and changes differently in the afternoon depending on ambient temperature: the human becomes vulnerable to heat stress in the afternoon.

3. The effect of climatic factors on the Core Interthreshold Zone (CIZ), with the onset of sweating and shivering, was presented. An experiment consisted of immersion in water with exercise at 50% leading to a measurement of the onset of sweating followed by stillness (no exercise) leading to the onset of shivering. Measurements of skin temperature indicate vasoconstriction or dilation in the interthreshold zone. First skin temperature drops while core temperature remains constant. This leads to shivering and an increase in O_2 consumption. The core temperature drops when the skin temperature becomes stable. Other experiments consisted of the use of water-perfusion suits and the analysis of differences between twins (for a genetic basis) and differences between lighting conditions. Measurements were taken with lighting at 18 cd/m^2 and 36 cd/m^2, with different results between Summer and Winter, which raised the question: does lighting affect body temperature? The effect of light would be by (1) non-visual pathways in response to visual stimuli and (2) afferent information from total body surface via non-visual pathways. Hence the behaviour of the interthreshold zone is required for modelling.

Discussion[*]

It was noted that the temperatures considered were much higher than those experienced in the United Kingdom. The question of the effect of climate on persons with disturbed circadian systems was raised, e.g. for night-time shift workers. Sleep disorder had been looked at with respect to persons not waking up and to differences in temperature. The treatment for such patients is by exposure to bright light (effective, though the timing is difficult).

In terms of heat acclimatisation, the higher threshold for sweating[3] was questioned. There is a difference between short term and native population adaptation. (When people are not adapted to the heat for long, for example, at the beginning of Summer, they sweat a lot when exposed to the heat. One may observe a lot of dripping sweat as well that does not contribute to heat loss by

[*] Contributions to this discussion from George Havenith, Peter Bröde, John Johnson and Mike Tipton are acknowledged.

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evaporation. This response must be called “a less good adaptation”. Once people get adapted like people in South Asia, they do not sweat easily while in the heat to avoid loss of body fluid. When the body temperature becomes high enough, they sweat a lot with less dripping sweat to increase the amount of heat loss by evaporation.)

Use of lighting to improve sleep was discussed, noting that baths in the evening also had a positive effect on sleep. An increase in body temperature (by bath) does help with a heat loss enhancement suggested to have an optimal effect on temperature decrease during sleep.

‘*Thermophysiology and ageing*’

James Goodwin *(keynote speaker 7)*

Ageing, a cause of vulnerability for an important population group, was presented by James Goodwin with the following topics: demographic change, conceptual revolution in ageing, biology of ageing, thermophysiology and age and the implications of the above. Ageing is an unprecedented global phenomenon. It shows little sign of ending and life-expectancy will continue to break records. Ageing well means a reduction in morbidity. Ageing is not a disease and it may be slowed down. Techniques such as telomerase reactivation, calorie restriction mimetics and antioxidant therapies are current areas of research to slow down the ageing process.

In terms of thermophysiological ageing, homeostatic responses decline; for example, regulation of blood pressure after standing up is impaired when in older subjects. Experiments of the transition from a warm to a cold environment can result in a systolic blood pressure > 200 mmHg for the aged. Cardiovascular autonomic reflexes become impaired with age because of changes in the nervous system. Failure to maintain heat balance is also linked to impaired homeostasis; for example, maintaining salt and water balance becomes more difficult with age and there is a slower sweating rate over the age of 75. Additionally, salt and water disorders are more common in older people, especially after the age of 75 where there is a high prevalence of comorbidity. The effect of heat (mortality) is different in different regions of the United Kingdom, but is immediate (no lag) in all regions. Heat presents important risks to the cardiovascular system and the greatest risks to the elderly. The indoor and outdoor effects are both factors of risk.

Recommendations were made towards:

- making more use of existing evidence;
- better interdisciplinary work.

Physiology models could be based on cytology models but would also need to include co-morbidities and ageing. How social conditions affect health impacts is not well researched and the Paris heatwave of 2003 revealed there is a need for more case histories. Research requirements were expressed for:

- modelling to improve preventative measures;
- behavioural research – for all levels, from the health care system to populations.

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Discussion[*]

It was asked: where does age per se stand with respect to disease? Chronological age should only be used as a guide. Though ageing is not a disease, there are commonalities between the ageing process and many pathologies. Age is the common risk factor in all chronic long term illnesses. It should be the ageing process that is used as a variable in terms of impairment in homeostasis. For this, there is a need for more research on post 75 year olds. Age would not necessarily be a sufficient parameter for a model but only a rough benchmark.

It was noted that the reduction in morbidity and mortality due to cold will continue in the future but that there is now a much faster change in climate such that the threats will be very different in the future. As far as risk is concerned, 12 ℃ is the threshold for cold for respiratory physiology; there will still be an important risk due to cold, especially with an ageing population. It was also noted that core temperature remains the same even for older people, and though the age-related changes in response to heat are known, there are few data on thresholds for these responses.

'*Calculating and modelling heat exchange in relation to thermal comfort, and the European COST Action on the Universal Thermal Climate Index*'

Peter Bröde *(keynote speaker 5)*

Peter Bröde's area of work is concerned with physical stress (climate and noise). Research on climate and noise is funded by the European Union (EU), and climate research includes projects on heat strain in protective clothing (Thermprotect) and the UTCI (Universal Thermal Climate Index). Peter Bröde presented the UTCI which had been recently developed using an advanced thermophysiological and heat exchange simulation model.

Initiated by a workshop of Commission 6 of the International Society of Biometeorology in 2001, and funded by the European Union within the COST Action 730, the development of the Universal Thermal Climate Index UTCI aimed at the assessment of the outdoor thermal conditions in the major fields of human biometeorology, e.g. public weather services, public health systems, urban planning, tourism and recreation and climate impact research. The UTCI provides a simple, one-dimensional characteristic of complex thermal environments as determined by air temperature, heat radiation, humidity and wind speed. The assessment should be based on the physiological response of the human body, which in turn was to be simulated by a state-of-the-art thermo-physiological model.

The EU COST[†] working groups include physiology modelling, meteorological measurement and applications. After accessible models of human thermoregulation had been evaluated, the advanced multi-node 'Fiala' thermoregulation model[4] was selected, extensively validated with 274 persons and 59 conditions[5], and extended and adapted for purposes of the project

[*] Contributions to this discussion from John Johnson, Paul Wilkinson and George Havenith are acknowledged.

[†] www.utci.org

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resulting in a 200 node model. In the next step a state-of-the-art adaptive clothing model[6] was developed and integrated. This model considers (1) the behavioural adaptation of clothing insulation observed for the general urban population in relation to the actual environmental temperature, (2) the distribution of the clothing over different body parts providing local insulation values for the different model segments, and (3) the reduction of thermal and evaporative clothing resistances caused by wind and the movement of the wearer, who was assumed walking 4 km/h on the level.

UTCI was then developed following the concept of an equivalent temperature, thus relating the index value to the familiar temperature scale. This involved the definition of a reference environment with 50% relative humidity (but vapour pressure not exceeding 2 kPa), with still air (v_a = 0.5 m/s) and mean radiant temperature equalling air temperature, to which all other climatic conditions are compared. Equal physiological conditions are based on the equivalence of the dynamic physiological response predicted by the model for the actual and the reference environment. As this dynamic response is multidimensional (body core temperature, sweat rate, skin wettedness, etc., at different exposure times), a strain index was calculated by principal component analysis as single dimensional representation of the model response. The UTCI equivalent temperature for a given combination of wind, radiation, humidity and air temperature is then defined as the air temperature of the reference environment, which produces the same strain index value. Based on criteria developed from the simulated physiological responses, the UTCI values were further categorised into ten categories of thermal stress ranging from “extreme cold stress” to “extreme heat stress”[7].

As calculating the UTCI equivalent temperatures by running the thermoregulation model repeatedly would require a special expertise and could be too time-consuming, e.g. for climate simulations and numerical weather forecasts, several options to simplify this calculation were considered. These included look-up tables of pre-calculated index values for a grid of all relevant combinations of climate parameters and polynomial regression equations predicting the UTCI equivalent temperature values over the same grid.

The operational procedure, which is available as software from the UTCI website (www.utci.org), showed plausible responses to the influence of heat radiation and humidity in the heat[8], as well as to wind speed in the cold and was in good agreement with the assessment of ergonomics standard concerned with the thermal environment. Further verification of its application to the analyses of urban outdoor thermal comfort was carried out by the interviewing of 944 male and 710 female pedestrians and micro-climate measurements[9]. Evaluation of the predicted versus actual thermal sensation found good correlations for the reference conditions (correlation r = 0.62), for the actual climate and for the actual climate with clothing, though for the latter the correlation does not improve (r smaller). Though the error is greater in the colder season, absolute bias was less than 0.3 points with root-mean-squared errors of less than 1 point on the 7-point thermal sensation scale. These responses to cold and heat stress suggest that in this regard UTCI may be universally useable in the research and in the major areas of application of human biometeorology.

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It was found that the validation and error analysis were very important and as time-consuming as model development, that developing and testing of separate sub-models, clothing, inputs, etc., were required and that possible errors in the final coupled-model due to meteorological errors were examined. The advantages found were that the detailed physiological model provides flexibility, universality and extensibility, and that the model provides the opportunity to account for effects of local cooling[10], activity levels and physiological adaptation. However, the application of a sophisticated simulation model requires more detailed input and the extension to special sub-populations, e.g. vulnerable groups, needs to take account of possible differences in the thermoregulation system as well as in behavioural and psychological adaptation.

Discussion[*]

It was noted that a complex model was addressed by this presentation, including a description of physiology and clothing. The model needs only the input of weather data, but this may cause a problem. The estimation is through interpolation and using a function. The model is only for the total population and not for specific groups. Systematic variations in metabolic rate, clothing (against temperature) and exposure time must be considered, these all add extra complexity. The question was raised about interactions (physiological) between input variables, but interactions are covered by the physiological model, which allows one to simulate the non-linearities. This is why there is an important model validation.

The requirements for the weather data required to run the UTCI was discussed. The UTCI requires only four basic parameters. However, there is a difference between wind at 2 m and the standard meteorological 10 m. The 2 m measurements would need to be transformed to 10 m for input to the UTCI.

'*Final thoughts; the limitations and opportunities of mathematical modelling*'

Matthias Heil *(keynote speaker 8)*

Matthias Heil provided a summary of the workshop's first day. He noted that some of the existing modelling was impressive. There was an assumption as to what the Met Office wanted from the workshop[†]: the perception was that the Met Office is good at producing data and is interested in producing useful numbers such as those that can be used by a health service.

There are problems with modelling a complicated system: there is a near infinite number of input parameters and there is a need to obtain something measurable and useful. It was asked if disease could be represented by changing parameters in the model. There is a framework (UTCI) of input/output but the underlying physiology cannot be improved because it is closed software: therefore access to the source code would be needed.

[*] Contributions to this discussion from Matthias Heil, George Havenith, John Johnson and Ken Parsons are acknowledged.

[†] Note: the workshop was organised jointly by the University of Exeter and the Met Office to "help formulate the research questions to be addressed" in the field of Heat and Human Health (c.f. www.exeter.ac.uk/metoffice/heatandhealth).

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Perhaps patient-specific modelling should not be done and it is better to use epidemiology. To generalise (patient-specific modelling to populations), stochastic modelling may be used for populations – this is currently topical in the Mathematics community. The statistics approach is underappreciated but depends on how much data is available. Raw data may provide an indication of vulnerability of different groups. Maybe not enough is made of the data.

Discussion[*]

It was noted that unfortunately the models are valuable and are closed source. It may however be possible to reopen the physiological model underlying UTCI.

3. Questions to be addressed

Breakout sessions provided opportunities for discussion along different themes and addressed questions raised during the plenary sessions.

From a physiology / health care / patient experience perspective

chaired by Patrick Sachon

These two breakout groups were focused on the problem of Heat and Human Health from the perspective of the Healthcare providers / professional and the patients.

There were two sessions attended by broadly similar groups, although there was some interchange. In general the first session was attended by the members of the workshop who were healthcare professionals, or those who lead research in this area. A number of those with other interests joined the second workshop. A large number of discussion points and ideas were generated in the first session and these were short-listed and refined during session two.

The focus of discussions was around the following, and these questions reflect the main outputs from the group in respect of future research questions:

- Who is really at risk?
- How will these risk groups change in a changing climate?
- How do we target these people effectively in a cost effective way?
- What actions can people take to reduce the risks to their health from heat or cold?
- How we can persuade people to change their behaviour?

Underpinning all of the above was a discussion regarding how much new work was required initially to answer the questions above. It was considered by most members of the group that there was a lot of work ‘out there’ that needed to be mined first before new work was initiated.

[*] A contribution to this discussion from George Havenith is acknowledged.

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From a physics / mathematics and modelling perspective

chaired by Christophe Sarran

Pre-lunch session: The first breakout group of this theme focused on the capabilities of modelling thermophysiological effects. Three main items were discussed:

- the modelling of an individual within his/her environment (indoor/outdoor),
- the possibilities of transferring the physiological model of an individual to a population-scale model, and
- the use of model output by an end user.

It was noted that the risk due to heat that an individual incurs can be evaluated by simulating the causal processes between heat and the specific risks (based on physics and chemistry), e.g. the modelling of moisture loss and the link with disease. Such models of human response depend on the specific environmental conditions including the micro-climate indoors. Modelling the indoor environment in buildings is understood but modelling the physiology of an individual placed within a building would have the potential to deliver much needed information on the risk to individuals inside a building. It was further discussed that a model of human physiology is likely to hold too many parameters and that it would be necessary to extract essentials (e.g. temperature, relative humidity, radiation, etc.). The use of only a few parameters would help in deriving an index; however, a model would not have sufficient flexibility if it were too simple – i.e. more complex models would be easier to adapt for specific risks and specific population subgroups.

Thermophysiology models at an individual's level were differentiated from population models. How well an individual physiological model represented the effect on a population was discussed. It was determined that while a physiological model may provide information on the risk for an individual at a specific place and time, it was not necessarily suitable for assessing the risk in an epidemiological sense, i.e. at the scale of populations composed of millions of individuals. This is partly because each individual within a population presents different characteristics and therefore different population subgroups are at risk in different ways. It was however noted that it would be possible to transfer thermophysiology model results to meaningful information for a population by using the probability distributions of the population characteristics and running Monte Carlo simulations. Furthermore, the modelling of individual subgroups could also be achieved once the parameters characterising the groups were determined.

It was suggested that while the model output could be a single number (or index), a significant amount of education would be required for the end user to be sufficiently confident in the interpretation of that number to take effective action. Hence in terms of the end user, statistical models (based on epidemiology) provide much simpler predictors.

Afternoon session: The second breakout group of this physics, mathematics and modelling theme was attended by participants with more

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healthcare and physiology backgrounds*. Objectives were to range outcomes from the 1st break out session in terms of perceived usefulness and then to contrast these outcomes in terms of achievability.

It was noted that a model would be useful but there is complexity, covariance, confounded by medication and pathologies. It was suggested that an index of susceptibility to heat stress could be defined, hence characterising low and high risk population groups: it would be necessary to determine the criteria for threshold between high and low risk groups. It was asked whether or not epidemiology existed to determine a scale (of risk). While a useful scaling system may be derived, it was not clear what use would be made of it.

It was then discussed whether interventions using drugs could be designed (e.g. aspirin in a heatwave). It was noted that using a probe to monitor core temperature is not practical; using the relationship between heart rate and heat loss would however be feasible given a model of cardiac output. It was also mentioned that there is a combination of comorbidities. There would be a need to use in-hospital databases to access data for groups of populations. A prospective drug study would measure the effect of drugs in heatwaves.

4. Suggested research

Summary of break-out groups of 5th April

- What are we trying to achieve?
  - Improving the lives of vulnerable people
  - Avoiding excess mortality
- Challenges
  - Understanding how to help people change their behaviour
  - Understanding who is at risk and how to target the vulnerable
  - Understanding how the distributional change in climate will affect health risk

The breakout groups agreed that the ultimate goals of research in the field of heat and human health are to reduce morbidity and mortality. To achieve these it was determined that it was important to:

- identify – and characterise – the population sub-groups (e.g. disease groups, older people) that are particularly vulnerable to heat stress;
- verify by measurement that the definition of vulnerable sub-groups correctly assigns susceptibility to risk;
- develop a heat-health index with a threshold to be used by the building industry for new designs and adaptation of older buildings;
- adapt this heat-health index for special buildings occupied by specific users such as schools, hospitals, care homes, etc.;
- adapt existing models for specific vulnerable groups of the population;

* Contributions from John Johnson, Clare Thorn and Gerald Kierzek are acknowledged.

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- develop the mathematical methods to obtain modelling results for whole populations (or population sub-groups) from the physiological modelling of individuals*;
- design effective interventions that help people change their behaviour in a targeted way (e.g. with targeted communication channels such as those used by the Met Office COPD service);
- determine how the health risk will change with a changing climate.

As a result, five initial research proposals were discussed by the workshop participants.

Ideas for research proposals

- Development of a simple index to categorise individuals according to their susceptibility to risk
- Prospective study to measure health outcomes of vulnerable individuals during Summer to determine who is at risk
- Development of a 'heat health' index and threshold for the building industry
- Further development of existing heat-balance models (e.g. UTCI) to model specific population sub-groups
- Possible prospective drug intervention in the event of a heat-wave (preventative treatment of individuals at risk and change in other treatments)

5. Research and development recommendations

The Heat and Human Health workshop provided the means of determining the approach that should be taken before and towards developing and using models of thermophysiology. In particular, three areas of work were highlighted:

1. **Reviews, meta-analyses and epidemiology.**
2. **User value and service delivery and effectiveness.**
3. **Physiological models and their outputs, indices and thresholds.**

It is the third of these that the Heat and Human Health workshop aimed to address in terms of existing models that can already be used and models that would be useful to develop. The following questions are gaps that have been identified by the workshop:

- What is the thermophysiological response of a vulnerable individual to heat/cold?

This question stems from the ethics of experimenting on vulnerable people. It is most often the case that measurements of this nature cannot be taken. Study of the physiological response can only be carried out by simulating the physiology with a model with the characteristics of the vulnerable individual. This could be done by adapting an existing model. It would then be possible to simulate the response to heat or cold of a vulnerable person with verification carried out using retrospective clinical databases where appropriate.

* Mostly respresenting the "average" person in the population group or sub-group.

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- What are the cardiovascular and respiratory risks from heat and cold stress, how are these caused and how can these be reduced?

Determining the cardiovascular risks statistically does not examine the causal physiological mechanisms that generate that risk. It is therefore valuable to gain further understanding of the effect of heat and cold stress on the cardiovascular (and respiratory) system, and the mechanisms by which heat and cold have an effect including circadian effects*, by modelling the cardiovascular system in conjunction with a heat balance model. It is estimated that this could be realistically achieved, and in such a way that it can be adapted to simulate the cardiovascular system of persons with specific diseases, e.g. atherosclerosis, thus addressing the modelling of vulnerable groups. More significantly, it would also address the risk of health impact (cardiovascular) which many more people suffer during a heatwave than the risk of acute heatstroke.

- What is an acceptable quantified threshold† for heat inside a building?

Buildings provide shelter from the outside environment and this should include protection from heat during heatwaves. Currently there are no building design specifications related to heat-health. With the increasing interest in Health Impact Assessment (HIA) for neighbourhood planning and building design, heat-health will play a prominent aspect of designing healthy buildings. It is therefore necessary to quantify the health risk from heat by modelling old and new building designs within weather and climate models, and placing physiological (heat balance) models of persons within the building models. These studies will need to be refined for vulnerable groups where appropriate, e.g. for care-homes.

- What is the relationship between output from physiological models and the effects on vulnerable populations?

Individual physiological models are not necessarily representative of population effects. At one level an individual model will provide the physiological response for an average human being within specified environmental conditions; at another level the distributions of the characteristics of members of a population will strongly influence the response of the population as a whole given environmental conditions. The population response may be significantly different from the individual response in such a way that individual models on their own would not yield sufficient information to be used to deliver a health warning service. With the distributions of population characteristics, the population response could be inferred mathematically from individual physiological models using Monte Carlo and stochastic methods. The development of means to transfer output of individual models to population models is key to bridging the gap between the measurement of health risk through physiological mechanisms and the delivery of an effective health warning service.

* The circadian rhythm of body temperature may be a useful index to predict the magnitude of vulnerability to heat because the circadian rhythm of body temperature may reflect the strength of the individual's cardiovascular system.

† And the placement of this in an industry-standard thermal model.

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- What are the preventative measures that could be taken to reduce morbidity and prevent mortality in individuals sensitive to heatwaves?

Drugs are designed to treat specific conditions and modify aspects of physiological function. On the one hand there may be some drugs that could administered to counter physiological effects of heat, on the other hand patients may already be taking drugs with side-effects that may be exacerbated by excessive heat. In the latter case it becomes important to examine what these undesirable side-effects are and determine means of adjusting treatment as a result of forecast heatwave periods, for example for the class of atropine-like drugs that could inhibit sweating. This could develop into a valuable warning service that would reduce morbidity. Health promotion, i.e. changing behaviour (at both an individual and population level), could be just as effective as a pharmacological intervention. An example of this would be smoking where a combination of legislation and health promotion is slowly mitigating its effects. Furthermore, the identification of interventions that could be used to prevent the health impact of heatwaves on people with cardiovascular and respiratory conditions would help in reducing morbidity and mortality of vulnerable populations. For example, aspirin is an antipyretic in the case of fever, but will not have any effect on hyperthermia due to environmental heating or exercise. Its major benefit in that case would be as an anticoagulant. This would require, on the one hand, the identification of both helpful and harmful sorts of interventions because that information is important in a heatwave and, on the other hand, a prospective study (such as a clinical trial for a pharmacological intervention) to verify the efficacy of such interventions in conjunction with meteorological forecasting of heatwaves.

- How will the health-risks change as a result of a changing climate?

It has been stated that climate change is expected to have accelerated: thus adaptation may now be more difficult. The health risks due to poor adaptation and an increase in frequency of extreme heat events mean that the health impacts of heatwaves will change. However, the increase in mortality due to an increase in heatwaves may be largely compensated by a reduction in mortality due to a decrease in the number of very cold periods – yet it is not clear whether this is the case (e.g. behaviour change may mean that the impact of cold weather will be greater in the future). With an ageing population, many thousands become more vulnerable, so even if there are fewer very cold Winters, it may be that excess Winter mortality will not decline any more rapidly than at present. There is a need to model the direct impact of heat and cold on the human physiology, so as to attribute changes to the risk to changes in behaviour and hence model the future health impact of weather events in a changing climate.

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Outcome from plenary session of 6th April

- Drug effects
  - Review of existing studies (meta-analyses) of the impacts of medicines/drugs on heat-health risks
  - How much of impact is attributable to disease and to drug treatment
  - Potential for prospective studies
- Proposals suggested are strongly interdisciplinary – a challenge to satisfy expert scrutiny
  - Building research
  - Population studies
  - Modelling and intervention studies
- Using models of individuals to study characteristics of populations
  - Concern that individual model would not represent population effects
  - Feasible use of stochastic methods to generate characteristic distributions for populations
- Using open-source of a heat-balance model would allow enhancements of model to specific population sub-groups
  - UTCI equations are published
  - Partner with UTCI code proprietors for a model enhancement project for a specific clinical sub-group

The nature of the proposed research and development work presents two important challenges:

(1) The interdisciplinary nature of the proposed work, drawing on expertise from various fields (physiology, architecture, meteorology, medicine, etc.), means that many resulting collaborative project proposals will need to satisfy the peer-review processes in two or more disciplines to draw suitable funding – there may be significant difficulties for experts of one discipline to fully appreciate the requirements for a project from a different discipline. Furthermore, the workshop was an international forum for the advancement of research and development in the field of Heat and Human Health: funding from national institutions may place restrictions on which universities and organisations may access this funding.

(2) While the issue of transfer of individual model output to population model has been explicitly expressed as a research question, it remains a significant challenge because, until resolved, it prevents the direct use of individual model output to model population effects and subsequent health warning service delivery. It is therefore a research question that must be addressed if the full value of thermophysiological models is to be reaped.

Despite these challenges, the members of the Heat and Human Health workshop and their affiliated institutions recommend that the research and development questions stated here are actively pursued.

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6. Collaborative research proposals

Suggested collaborative proposals to address each research question are listed here. These proposals are only suggestive and their objectives need to be more precisely defined at a later stage.

All of the following could be progressed individually, or in the sub-themes into which they have been organised. However, a more sustainable approach would be to collate as many as are feasible together into an overarching programme proposal, perhaps under the aegis of a COST project.

What is the thermophysiological response of a vulnerable individual to heat/cold?

1. Adapt and validate the UTCI (Universal Thermal Climate Index) to model vulnerable individuals.

Suggested investigators:

Peter Bröde	IfADo Dortmund
Dusan Fiala	ErgonSim Stuttgart
George Havenith	Loughborough University
Kalev Kuklane	Lunds Universitet
Angela Shore	Peninsula College of Medicine and Dentistry

2. Develop a simple index to categorise individuals according to their susceptibility to risk – based on existing databases and epidemiology.

Suggested investigators[*]*:*

Phillip Gates	Peninsula College of Medicine and Dentistry
Paul Wilkinson	London School of Hygiene and Tropical Medicine

3. Prospective study to measure health outcomes of vulnerable individuals during the Summer and heatwaves.

Suggested investigators[*]*:*

Jon Ayres	Birmingham University
James Goodwin	Age UK
Gerald Kierzek	Cochin Hospitals University
Patrick Sachon	Met Office

[*] Including researchers from the European Centre for Environment and Human Health (Peninsula College of Medicine and Dentistry).

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What are the cardiovascular and respiratory risks from heat and cold stress, how are these caused and how can these be reduced?

4. Develop a cardiovascular circulation model that interacts with a heat balance model.

Suggested investigators:

Peter Ashwin	University of Exeter
Phillip Gates	Peninsula College of Medicine and Dentistry
George Havenith	Loughborough University
Naoshi Kakitsuba	Meijo University
Kim Parker	Imperial College
Christophe Sarran	Met Office
Gavin Tabor	University of Exeter
Philippe Young	University of Exeter

5. In vivo measurements of cardiovascular response to heat and cold stress – cardiovascular heat balance model validation.

Suggested investigators:

Jon Ayres	Birmingham University
Phillip Gates	Peninsula College of Medicine and Dentistry
George Havenith	Loughborough University
Naoshi Kakitsuba	Meijo University
Angela Shore	Peninsula College of Medicine and Dentistry
Gavin Tabor	University of Exeter
Mike Tipton	Portsmouth University
Philippe Young	University of Exeter

What is an acceptable quantified threshold for heat inside a building?

6. Model the distribution of heat inside buildings interacting with weather and study the response of heat balance model of individuals placed within the buildings.

Suggested investigators:

David Coley	University of Exeter / University of Bath
Mark McCarthy	Met Office
Christophe Sarran	Met Office
Angela Shore	Peninsula College of Medicine and Dentistry
Gavin Tabor	University of Exeter

7. Develop an indoor heat-health index and threshold for buildings.

Suggested investigators:

Gwangyong Choi	Jeju National University
David Coley	University of Exeter / University of Bath
James Goodwin	Age UK
Ken Parsons	Loughborough University

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8. Examine the distribution of heat in a hospital and its impact on patient morbidity – in particular during heatwave conditions.

Suggested investigators:

Dan Bloomfield	University of Exeter
David Coley	University of Exeter / University of Bath
Gerald Kierzek	Cochin Hospitals University
Christophe Sarran	Met Office
Angela Shore	Peninsula College of Medicine and Dentistry
Gavin Tabor	University of Exeter

What is the relationship between output from physiological models and the effects on vulnerable populations?

9. Review of the effect of population behaviour on exposure of individuals to different environments (indoor/outdoor) – measurement of the link between behaviour and exposure where needed.

Suggested investigators[*]:

Charles Abraham	Peninsula College of Medicine and Dentistry[†]
Gwangyong Choi	Jeju National University
James Goodwin	Age UK
Naoshi Kakitsuba	Meijo University
Paul Wilkinson	London School of Hygiene and Tropical Medicine

10. Develop mathematical method for a population model of heat stress[‡] from a physiological model of individuals[§].

Suggested investigators:

Peter Ashwin	University of Exeter
Peter Bröde	IfADo Dortmund
George Havenith	Loughborough University
Matthias Heil	University of Manchester
Christophe Sarran	Met Office

11. Develop heatwave warning service based on population (physiological) models of heat stress.

Suggested investigators:

Gwangyong Choi	Jeju National University
James Goodwin	Age UK
Gerald Kierzek	Cochin Hospitals University
Patrick Sachon	Met Office
Paul Wilkinson	London School of Hygiene and Tropical Medicine

[*] Including researchers recommended by Nagoya Institute of Technology.
[†] Behaviour change group.
[‡] By considering the population variability in the response to heat stress.
[§] Using already collected data or data collected as part of another of the suggested proposals.

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What are the preventative measures that could be taken to reduce morbidity and prevent mortality in individuals sensitive to heatwaves?

12. Review of the interaction of treatments with environmental conditions.

Suggested investigators[*]*:*

Jon Ayres	Birmingham University
David Halpin	Royal Devon and Exeter Hospital
John Johnson	University of Texas Health Science Center

13. By first confirming which treatments are affected using epidemiological data, develop adjustments to treatment of patients where the treatment interacts with heatwave conditions resulting in an exacerbation of side-effects – these adjustments would help reduce morbidity – this may require a clinical trial.

Suggested investigators:

David Halpin	Royal Devon and Exeter Hospital
Patrick Sachon	Met Office
Angela Shore	Peninsula College of Medicine and Dentistry
Clare Thorn	Peninsula College of Medicine and Dentistry

14. Identify possible drugs with heat protective effects (e.g. from epidemiological studies) and carry out prospective drug intervention to prevent morbidity and mortality of vulnerable people in the event of a heatwave – clinical trial in conjunction with heatwave forecasts to prove efficacy.

Suggested investigators:

John Johnson	University of Texas Health Science Center
Patrick Sachon	Met Office
Angela Shore	Peninsula College of Medicine and Dentistry
Clare Thorn	Peninsula College of Medicine and Dentistry

How will the health-risks change as a result of a changing climate?

15. Develop the interaction between physiological models and climate models to quantify the impact of climate change on health risks.

Suggested investigators:

Peter Ashwin	University of Exeter
Dan Bloomfield	University of Exeter
Peter Bröde	IfADo Dortmund
Gwangyong Choi	Jeju National University
David Coley	University of Exeter / University of Bath
Mark McCarthy	Met Office
Mike Tipton	Portsmouth University
Kate Willett	Met Office

[*] Including researchers from the European Centre for Environment and Human Health (Peninsula College of Medicine and Dentistry).

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